STRATEGY RESEARCH PROJECT

A COMPLEX DRAGON IN A CHAOTIC SEA: NEW SCIENCE FOR USMC INFORMATION AGE DECISIONMAKERS

BY

LIEUTENANT COLONEL ROBERT R. LOGAN
United States Marine Corps

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Lieutenant Colonel Robert R. Logan
United States Marine Corps

Colonel Andrew J. McIntyre, Jr.
Project Advisor

U.S. Army War College
Carlisle Barracks, Pennsylvania 17013

ABSTRACT

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This paper explores the applicability of the "new sciences" of nonlinear dynamics, deterministic chaos, and complex adaptive systems to the analysis and design of military decisionmaking processes for the information age. It begins with a review of Newtonian scientific concepts that created a worldview of system behavior still dominant today. The emergence and tenets of the new sciences are then developed with emphasis on nonlinear systems and their unique characteristics. A model of the military decisionmaking process associated with military command and control is then presented in terms of an information feedback system. This model shows the nonlinearity of such systems and the impact of their chaotic and complex attributes. Finally, the United States Marine Corps' information age concept of advanced warfighting, "Sea Dragon," proves well suited for a decisionmaking process designed with new science principles in mind.

Introduction

This paper explores the applicability of the "new sciences" of nonlinear dynamics, deterministic chaos, and complex adaptive systems to the analysis and design of military decisionmaking processes for the information age. It begins with a review of Newtonian scientific concepts that created a worldview of system behavior still dominant today. The emergence and tenets of the new sciences are then developed with emphasis on nonlinear systems and their unique characteristics. A model of the military decisionmaking process associated with military command and control is then presented in terms of an information feedback system. This model shows the nonlinearity of such systems and the impact of their chaotic and complex attributes. Finally, the United States Marine Corps' information age concept of advanced warfighting, "Sea Dragon," proves well suited for a decisionmaking process designed with new science principles in mind.

A Clockwork World

On 28 April 1686, Sir Isaac Newton presented his three-volume *Philosophia Naturalis Principia Mathematica* to the Royal Society of London.[1] Since that date, he has held an unprecedented scientific position in history. He had discovered the laws of celestial order in the universe and as importantly, presented them so all could understand.[2] As a result, his three laws for the mechanics of all motion spread throughout the world.[3]

- If no forces are acting, a body remains at rest or moves uniformly in a straight line.
- Its acceleration is proportional to the force that is acting.
- To every action there is always an equal and opposite reaction.

Newton's laws marked the beginning of mechanistic reductionism: mechanistic in the sense that the behavior of conservative[4] mechanical systems was deterministic and predictable;

reductionism in that an understanding of the parts of a system would reveal the workings of the whole. Newton's world was linear, supporting the property of supposition whereby the effect of the combined action of two different causes was the superposition of the effects of each cause taken individually.[5] The universe was a clockwork and the clock maker was "infinitely rational, his works were totally predictable, and a few simple laws would reveal what made everything work."[6]

The paradigm of a law-based, cause-and-effect world grew throughout the eighteenth and nineteenth centuries as classical mathematical physics developed. Underlying laws emerged from Leibniz's calculus to Euler's partial differential equations. Lagrange's energy principles, Fourier's waveform analysis, and Laplace's potential theory, pointed toward causality. All phenomena were understandable when reduced to parts and the relating laws described.

Thinkers throughout industrial age societies adopted these principles to their environments. Practioners of the living fields of biology, psychology, and philosophy (not renowned as disciples of physics and mathematics) made widespread applications. Business and military organizations became *machine-like* systems. People were parts and the parts worked together through laws.

Why this worldview transferred to human organizations is significant. People had not ignored the *context* of Newton's philosophy; namely a linear, deterministic universe containing linear, deterministic systems. They too lived in a messy world where systems exhibited random behavior that disregarded cause-and-effect relationships and produced effects completely disproportional to their causes. Remarkably enough, their answers came from within the high walls of mechanistic reductionism.

Random processes were not random at all. They only *appeared* that way due to current limitations in human understanding. In 1780 Laplace suggested that given the existence of a demon with immense mental and memory powers, he could predict the future.[7] Nonlinear system concerns vanished as easily. Since mathematical models did not exist, systems were linearized via reduction. Nonlinear behavior was broken into sectors of approximate linear behavior and then analyzed using linear models.

Mechanistic reductionism prospered in the beginning of the twentieth century. Thermodynamics contributed its second law, declaring that natural processes always move toward an increase of disorder, or entropy. Only force could maintain order. Mathematicians developed stochastic processes - sequences of events decided by the influence of chance - as coequal with the mathematics of deterministic processes.[8] A system was either deterministic or random, creating a border between order and disorder.[9]

Through the 1920s, the Newtonian worldview had been immutable. Then something very small happened which rattled the foundation; the creation of quantum mechanics. Dr. John R. Gribbin, an astrophysicist from Cambridge University, describes quantum mechanics as:

> "...the fundamental underpinning of all modern science. They provide the *only* real understanding of the world of the very small. Quantum theory represents the greatest achievement of science. And yet, it makes some very strange predictions."[10]

Scientists like Einstein, Schrodinger, Born, Bohr, Heisenberg, and de Broglie led the revolution that replaced Newtonian mechanics for sub-atomic physics. Yet its principles were both difficult to understand and to accept. Schrodinger reacted to some of its puzzles with "I don't like it and I'm sorry I ever had anything to do with it."[11] Bohr stated, "Anyone who was not shocked by quantum theory has not understood it."[12] As such, quantum mechanics did not significantly alter society's Newtonian view.

- Simple systems behave in simple ways.
- Complex behavior implies complex causes.
- Different systems behave differently.[13]

The New Science

"Today the Newtonian pool table is shoved into a corner of the cosmic playroom."
- Alvin Toffler

The new science goes by many names: nonlinear dynamics, deterministic chaos, and adaptive complexity. Initial discoveries began in the 1960s, yet the field experienced a fifteen-year delay before acceptance by the scientific community. James Gleick, author of the 1987 best-selling chaos history, described the reaction of the scientists as "Incomprehension; resistance; anger; acceptance."[14] They were hesitant to move beyond physical experiments and mathematical models to accept a new operational basis for scientific investigation, the digital computer.[15]

Computer experiments into nonlinear dynamics generated information forms and perspectives collectively known as the "new science."[16] They were "not like Newton's laws; they were about the dynamics of macroscopic systems."[17] The behavioral characteristics of new science phenomena ran *counter* to the Newtonian worldview.

- Simple systems produce complex behavior.
- Complex systems produce simple behavior.
- The laws of new science hold universally.

Simple systems produce complex behavior

In 1961, Edward Lorenz, a meteorologist using computer experiments of predictive weather models, discovered a remarkable behavior of simple nonlinear systems. His iterative feedback model generated greatly different results when the starting values were only slightly different. This "sensitive dependence on initial conditions" became synonymous with Lorenz's "Butterfly Effect" metaphor: the flapping of the wings of a butterfly in Tokyo may cause a tornado in Oklahoma.[18] However, it was Lorenz's discovery of an underlying order in the computer-generated patterns of the system's seemingly random behavior that gave birth to the concept of deterministic chaos.

Unlike the normal usage of the word, new science "chaos" had an order visible only in the computer-generated world of phase space. Phase space portrayed the complete knowledge of a system's state as a point in space. As time progressed, the point moved as the state of the system changed. The trace depicted the life of the system. These "portraits of physical systems exposed patterns of motion that were invisible otherwise, as an infrared landscape photograph can reveal patterns and detail that exist just beyond the reach of perception."[19]

Computer experiments incorporating the topological mathematics of phase space representations paved the way for the rapid growth in nonlinear dynamics. Beginning with Lorenz, phase space diagrams uncovered regions or "strange attractors" where the plots of chaotic systems oscillated irregularly without settling down. Lauded as deserving the Nobel Prize, Lorenz's discovery sparked a "hunt for strange attractors" by researchers examining a wide range of nonlinear systems.[20] The answers were consistent; disorder remained constrained to patterns with some underlying theme.

During the late 1960s and early 1970s, Benoit Mandelbrot, an IBM researcher involved with the mathematics of patterns, found the structure behind chaotic phase plots. He did it while studying self-similar objects that had no characteristic length scales; they looked the same no matter the scale of measurement (snowflakes, coastlines, fern leaves, and clouds).[21] He called the structures "fractals" for their fractured structure and their spacial dimension that yielded a fraction value.[22] Tremendously rich and complex structures came from "simple" fractals.

The similarities between Lorenz's butterfly effect and Mandelbrot's fractals were more than coincidental. The fractal dimension directly linked to strange attractors as "governing various qualitative features of a chaotic dynamic."[23] Through deterministic chaos and fractals, simple "causes" could produce chaotic "effects." The "either/or" world and its boundary between determinism and randomism were now "both/and."

Chaos theory concludes simple nonlinear feedback systems have inherent behavioral characteristics: (i) *deterministic chaos*--seemingly random behavior having an underlying order; (ii) the *"butterfly effect"*--sensitive dependence on initial conditions.

Complex systems produce simple behavior

Ilya Prigogine won the Nobel Prize in 1977 for his work in nonequilibrium thermodynamics. His findings became the basis for the second family of new science phenomena: adaptive complexity, self-organizing systems[24], and nonequilibrium dynamics. Providing a "striking reinterpretation of the Second Law of Thermodynamics,"[25] Prigogine had discovered entropy was not merely a downward slide toward disorganization, but under certain conditions, could become the source of order.

Adaptive complexity addressed why certain systems run down, yet others simultaneously evolve and grow more coherent. All self-organizing systems were found to have self reinforcement. Positive feedback allowed small effects to become magnified when conditions were right instead of dying away.[26]

> "...when fluctuations force an existing system into a far-from-equilibrium condition and threaten its structure, it approaches a critical moment or bifurcation point. At this point it is inherently impossible to determine in advance the next state of the system. Chance nudges what remains of the system down a new path of development. And once that path is chosen (from among many), determinism takes over again until the next bifurcation point is reached."[27]

Imbalanced forces or nonequilibrium brought order out of chaos. Complexity researchers call this process *emergence*; from the system interaction at one level emerges a new global property at another level.[28] Nonlinear systems that do not experience fluctuations strong enough to force them away from equilibrium do not evolve. Only when they are "maintained an appropriate distance from equilibrium that multiple solutions . . . and hidden potentials are revealed."[29] The "perpetual novelty"[30] of self-organizing systems is not a series of transitions to optimal states. The best these systems can do is improve relative to existing conditions. A lack of determinism prevents models of self organizing systems to accurately predict outcomes. Rather they "simulate the processes that the systems will go through."[31]

Complexity theory concludes nonlinear feedback systems have inherent behavioral characteristics: (i) *self organization*--adaptation under threatening nonequilibrium conditions and (ii) *unpredictability*--any model of such a system is unable to predict the future state at the point of transition, it can provide insight as to the conditions necessary for change to occur.

The laws of new science hold universally

The previous paradigm divided the world into several camps: deterministic and random, reversible and irreversible, macro and micro. New science sees all behavior as intertwined. A dynamic world of emerging order replaces the clockwork world of increasing disorder. Disorder and nonlinearity are no longer problems but the source of adaptation and evolution.

The new science offers insights into existing systems and design considerations for the future. Recognizing the future as unpredictable, new science models seek a clearer understanding of nonlinear system behavior.[32] The remainder of this paper considers the military decisionmaking process in the light of the Newtonian and new science paradigms. In doing so, a compelling implication of new science analysis appears; the distinction between order and control.

The Decisionmaking Model

> "*The sciences do not try to explain, they hardly even try to interpret, they mainly make models. The justification . . . is solely and precisely that it is expected to work.*"[33]
>
> \- John Von Neumann

In contrast to Sun Tzu's fourth-century BC agrarian-age warfare philosophy, the early 1800s writings of Karl von Clausewitz reflected mechanistic reductionism.

> "The military machine . . . is basically very simple and very easy to manage. But we should bear in mind that none of its components is of one piece: each piece is composed of individuals, every one of whom retains his potential of friction . . . A battalion is made up of individuals, the least important of whom may chance to delay things and sometimes make them go wrong."[34]

While the war machine itself was predictable, its environment was considered a "dangerous realm of uncertainty and chance."[35] Like other reductionist of the time, military scientists considered the machine to be distinct from its environment. Military organizations were deterministic machines operating in a foggy, stochastic world. Like all machines, its internal friction was considered a function of the system controlling the parts.

The controller of the machine is its command and control (C2) system. Unlike the controlled resources (parts) of the organization, the C2 system decided general behavior. Configured as a closed-loop feedback control system,[36] its purpose is to reduce the difference between an actual and a desired state. The cycling energy is information, from raw data to processed decisions. Information concerning the actual state or environment is inputted to the decisionmaking activity. Once processed, decisions cause actions upon the environment.

Over the last twenty years, control theory diagrams have depicted C2 systems. Apart from minor modifications, they have remained unchanged. Models in 1970 reflected the influence of statistical analysis with its deterministic and probabilistic processing phases.[37] In the 1980s, Col Boyd's "OODA loop" reduced the process to its essential elements. The loop consisted of observing the enemies actions, orienting oneself to the unfolding situation, deciding on a counter, and then acting.[38] Recent Marine Corps diagrams show the same phases of the OODA loop, yet with a more interconnected feedback system.[39]

This approach has limitations. Static block flow diagrams only depict process sequence. They cannot depict *dynamics*; stable and unstable behavior, equilibrium versus nonequilibrium conditions, and regions of linear and nonlinear operations. While leaving an impression of deeper insight, they provide only a snapshot of system behavior, a single point in phase space. They also represent the information feedback loop in the limited context of standard control theory applications; as a source of control for linearity and stability (a damping vice amplifying feedback). The approach fails to highlight the loop's role in supporting positive feedback; the source of chaos and complexity.

The model for military decisionmaking as a closed-loop information feedback control system has the handicaps associated with creations of mechanistic reductionism. With these limitations in mind, though, the model can still serve as a familiar basis for further study of nonlinear dynamic behavior. The next section analyzes C2 system using the new science paradigm.

The Nonlinear Dynamics of Command and Control

New science applications are emerging in many areas. Some are direct: fractal image compression,[40] and applying chaos principles to control lasers, electronic circuits, and human hearts.[41] Others are metaphorical: nonlinear dynamics in the Bible,[42] the war on drugs,[43] and history.[44] Instead of attempting to analyze general warfare, this effort applies the new science paradigm to a military C2 system and decisionmaking process. Roger Beaumont, a chaos historian, commented on the distinction between this approach and that of an historian.

> "If nonlinear analytics helped in discerning the real limits of the ability to bring battle under rational centralized direction, it could set more realistic expectations regarding the influence of command-and-control technology, and help historians gain a clearer view of how confident they should feel in attempting to describe warfare."[45]

The analysis begins with a qualitative definition of dynamic behavior based upon information. When information becomes the energy that flows through the system, the reaction of the decisionmaking process to information is an indicator of system operation.

Linear and nonlinear system behavior would reflect whether proportionality and supposition existed between information input and decisions produced. The balance between information flow and decision processing would refer to the state of equilibrium. Using the "information as energy" concept, the main components affecting system dynamics become the processors (human element) and the transport system (information feedback network).

The Human Element: Decision Theory

The act of deciding is the nucleus of the decisionmaking system. Its study is the object of decision theory . . . "to provide a rationale for making wise decisions under conditions of risk and uncertainty."[46] As psychologist David Mandrel observes, its research results are principally from statistical analysis, not the new science.

> "Nonlinear, dynamical data-analytic techniques adapted for use in the behavioral sciences are currently scarce and may prove difficult to apply and interpret. Indeed, for most psychologists, who presently lack the mathematical sophistication necessary to fully apply nonlinear dynamical systems theory to the problems of psychology, it will probably, at most, offer some new conceptual insights."[47]

Lack of dynamic techniques, though, has not prevented the analysis of the human element of decisionmaking. Since the 1970s, the focus of research has moved away from the reductionistic idea of highly controlled experiments that isolated the system from its environment. New studies address how people make decisions in real life. The dynamic environment of real life decisionmakers involved risk, uncertainty, lack of structure, competing goals, lack of information, high stress, time compression, and feedback loops rather than single-decision events.[48] Classical findings have been widely refuted:

- Decisions are not made simply to maximize pleasure and minimize pain.[49]
- Decisionmakers evaluate potential outcomes not from a perspective of total wealth, but from a perspective of change in the status quo.[50]

- Decisionmakers are influenced by how information is presented (framed), not just its content.[51]
- Decisions for conservative or risky options are influenced by positive (gain) or negative (loss) framing.[52]
- Decisionmaking is not optimized when the "problem is decomposed and the results of the partial analysis are then recombined"[53]
- Decisionmaking violates the property of supposition. "Better decisionmaking does not arise from better information."[54]
- Decisionmakers are biased and do not give the same weight to different types of information.[55]
- Decisionmakers attempt to limit cognitive complexity by "focusing on the few or only on one salient aspect(s) of the situation at hand."[56]
- Decisionmakers are generally unaware of the rules that govern their impressions.[57]
- Decisionmakers believe information presented in a diagnostic manner is more reliable than other forms.[58]
- Decisionmakers process positive information less thoroughly than negative information where there is a "tendency to engage in more deliberate and careful analysis."[59]
- Decisionmakers tend to overweight options having low probability of occurrence while underweighting options that are more likely to occur.[60]

Naturalistic decisionmaking is *not* a linear, mechanistic process of option research and choice optimization. It is highly intuitive, where decisions are based upon such unquantifiable factors as experience and judgment. Classical analysis presents a model for decisionmaking under linear circumstances: calm environments where time and ambiguity are not factors. "Naturalistic" decisionmaking is the nonlinear model for environments of risk and uncertainty. When multiple nonlinear decisionmaking centers are interconnected through a military C2 system to form a dynamic environment, a nonlinear process having the full range of new science behaviors emerges.

The Information Feedback Network

Nearly identical decisionmaking processes embedded in identical environments exhibit radically different behavior.[61] The new science identifies this as deterministic chaos with its "sensitive dependence to initial conditions." The cause of the butterfly effect within the C2 system is the feedback network. Unlike the human element (the act of deciding), this is an area strongly influenced by technology of the information age. Even in the early 1970s, researchers anticipated the impact on the decisionmaking process by changes in feedback network technology.

> "The computer and communication revolution also promises to change decisionmaking in organizations by allowing top management to receive information from lower echelons much more quickly than previously. Such management information systems . . . appear to be *a coming thing*."[62]

At unprecedented speed, modernizations of the feedback network continuously increase the degree of connectivity and rate of transfer between decisionmaking centers. This affects the processing speed and energy flow within the network. The ability of the feedback network to effect nonequilibrium energy flow is the precursor for nonlinear dynamic behavior. Alvin Toffler described it as "helping to explain vicious circles -- and virtuous ones."[63]

Controlling Nonlinear Decisionmaking

New science presents a different concept of control. Its predecessor believed the future states of a system are directly controllable, if not predictable. The new science seeks to . . . "predict the qualitative nature of the whole system and the quantitative limits within which it will move."[64]

The classical view of system control has been to operate near the equilibrium point. In the decisionmaking analogy, this operating point occurs when the information (energy) flow is stable. Decisionmaking balances with information flow. Such balance is now difficult and will be harder in the future with increased interconnectivity, faster transfer rates, and the ever increasing dangerous nature of warfare. The new science considers this operating point a flawed choice. A system at equilibrium takes tremendous energy to change. On the other hand, a system operating in a nonequilibrium state near the "edge of chaos,"[65] takes little energy to change and adapt. Emergent order happens when a nonlinear system has the *freedom* to operate far from its equilibrium. This distinction between control and order has ramifications for designers of military C2 systems who want to "ride the technological changes through the coming century."[66]

Nonlinear Decisionmaking and "Sea Dragon"

> *"The Chinese have a saying that "change is a dragon." If you ignore him or control him, he will eat you. But if you can ride the dragon of change, you can survive, even prosper. I commit to all the people in this room that we're going to ride the dragon, and I'm going to seek your help."*
>
> \- General Charles C. Krulak,
> speaking to industry representatives

On 19 December 1995, the U.S. Marine Corps introduced the Commandant's Warfighting Lab (CWL) to defense industries. It is the focal point for the development of a new advanced warfighting concept, Sea Dragon.

> "The Sea Dragon concept is the future vision for accomplishing the overall Naval objectives of regional and littoral warfare. Its main tenet is the concept of dispersed, independent, and coordinated units ashore in conjunction with remote and timely fire power and logistics afloat that in total will achieve a dramatically more adaptive, effective, and far less vulnerable warfighting force . . . Sea Dragon presents a significantly revised approach to expeditionary warfare . . . and must take advantage of the wide range of current and emerging technologies."[67]

Past Naval Expeditionary Force (NEF) operations have required the buildup and protection of support and sustainment operations ashore. This has proven time-consuming to accomplish and highly vulnerable to attack. The goal of Sea Dragon is to significantly reduce the need for buildup ashore. It accomplishes this through four functional areas: dispersed independent small forces, sea-based and air precision fire, sea-based support and logistics, and increased mobility.

These fundamental changes require significant warfighting innovations. Several critical functional areas, or "long poles in the Sea Dragon tent," need substantial change or improvement.[68] Heading the list is command and control, which the Marine Corps refers to as "Command and Coordination" for Sea Dragon. Sea Dragon's C2 system will interconnect sea-based command elements and dispersed forces deployed ashore over hundreds of nautical miles. Connectivity will not follow traditional hierarchical lines but will fully integrate all deployed and supporting forces providing data flow over all echelons and between all systems. Distributed decisionmaking centers will need new automated capabilities.

> ". . . to employ automated decision support aids to accelerate the planning, decision, and execution cycle to increase operational tempo . . . to employ risk analysis in an accelerated planning, decision, and execution cycle . . . to employ near-real-time, embedded gaming and simulation during the planning process to evaluate alternative courses of action, the development of branches and sequels, and enhance the decision process."[69]

The Sea Dragon concept of the C2 system is far different from its predecessors. Changes to the human element and feedback network could alter the operational behavior of the system. Applying the new science paradigm to the Sea Dragon C2 concept provides a way to analyze the design from a non-Newtonian perspective. In doing so, potential problems and their solutions are considered. Subsequent analysis will focus on differences between the Sea Dragon concept and the preexisting model of decisionmaking.

The most obvious difference between Sea Dragon's C2 concept and prior concepts is its purpose: command and "coordination" rather than "control." A Sea Dragon commander is more like the leader of a jazz improvisation group than a conductor of a symphony orchestra.

He selects the key, sets the tempo, and then lets the jam session begin.[70] The next note played is unpredictable, yet the key and the beat provide an underlying order to the apparent chaos of improvisation. If the session appeared in phase space, the chaotic behavior would likely oscillate about the strange attractors of key and beat.

Sea Dragon's strange attractors are related to commander's intent and mission-type orders. Both provide the broad boundaries for autonomous and independent decisionmaking inside the C2 system. While this move toward coordination may have come from an impression that control would not be as effective because "dispersed units will not necessarily be controlled by any one person,"[71] the implications from new science are clear: nonlinear systems simply cannot be controlled in the classical sense.

The human element of decisionmaking changes under Sea Dragon. The decisionmaker will be supported by a new staff of automated systems: decision support aids, risk analyzers, and near-real-time gaming and simulation systems. How these systems actually change decisionmaking is directly related to problems each is designed to solve. One approach seeks to reduce the inherent nonlinear nature of the decisionmaker. Applications designed to linearize the decisionmaker would try to create faster and better decisions through faster and better information. Others would try to simplify the cognitive complexity of a problem by presenting decisionmakers with integrated risk assessments. Still others would attempt to predict the future through gaming and simulation of possible courses of action. While challenging, these changes would be going against the natural grain of the nonlinear system. From the new science perspective, their impact would be limited, if not doomed from the start to fall short of the potential available elsewhere.

The shift from prediction to understanding creates a new role for automation within the Sea Dragon C2 system; the use of computer simulation and gaming to characterize the dynamics of the system, not to predict outcomes. Characterization involves developing a dynamic picture of how the C2 system behaves under a variety of circumstances and over several feedback cycles; in effect a phase space diagram. The extensive use of simulation and gaming pushes a C2 system through its paces far more efficiently and effectively than conventional exercises. The primary intent would not be to train decisionmakers but to develop an understanding of how their system behaves. Rather than trying to find ways to control the system in an equilibrium mode, simulations force the system far from equilibrium and into regions of chaos and bifurcation. Though requiring significant effort from participating decisionmakers, the results would give insight into total behavior, system bounds, nonequilibrium operations, sensitivity to initial conditions, and transition states.

Phase space diagrams would depict the knowledge of the C2 system as a point whose state variables include network energy (information) distribution and processing (decisionmaking) status. During operational employment, commanders would use automated systems to see dynamic behavior and compare it to patterns from simulation. The C2 system maintains flexibility and adaptability operating at the edge of chaos. This would allow . . . "a variety of dynamic behaviors without requiring large controls or the design of separate systems for each desired behavior."[72] Automation provides the means of "creating chaos rather than ways to avoid it."[73]

Sea Dragon's information feedback web fully interconnects its distributed forces. Far different from current hierarchical military C2 systems, it supports accelerated decisionmaking cycles throughout the battlefield. From a mechanistic viewpoint, this robust system could be considered an ideal means to positively control the parts of the machine, especially important if the environment became chaotic. Commanders could control all the parts and with great enough force, cause major changes to occur. Entropy would be retarded, preventing the machine parts from deteriorating into disorder.

Practioners of new science see the richly interconnected, high speed feedback structure as a living Sea Dragon, not a machine. Consisting of negative and positive feedback, new science holds the potential for information to be the source of flexibility and emerging order. Instead of the hammer needed at equilibrium, the Sea Dragon C2 system operating near the edge of chaos only requires the application of small, judiciously chosen, perturbations to a system parameter to create change.[74] These perturbations could take the form of changes to information framing. System characterizations from simulation and gaming would identify the impact various framing strategies had on decisionmakers. During operation, this knowledge provides small modifications to the framing parameters of information needed for system-wide changes.

New science enables one to see new ideas for the first time and familiar ones from a different angle. Commander's intent and mission type orders become critically important as the basis of the nonlinear system's strange attractors around which the seemingly chaotic behavior is bounded. Continuity of the C2 decisionmaking team members now becomes the basis for establishing a thorough understanding of the system's characteristic dynamic behavior. Automation is no longer simply a means of doing current processes faster or trying to predict the future; it now focuses on understanding the present and creating new perspectives for commanders to see the behavior of their C2 system. Information is no longer a commodity of power for allocation and control; information is energy, free to flow throughout the system as the source of adaptation and creation.

The Sea Dragon C2 system would function on knowledge-based trust. If the environment became turbulent and chaotic, the nonlinear Sea Dragon commander would resist the urge to clamp down on information. He would trust in the inherent order provided by the strange attractors of intent and mission orders. He would trust in the fractal quality of his decisionmakers, each with the same values, to provide the "globally stable, though locally changing"[75] character of the self-organizing system. As Professor Czerwinski of the National Defense University put it, the Sea Dragon commander would trust his "Command by Influence" instead of control.[76]

SUMMARY AND CONCLUSIONS

"We're all going to make it up as we go along, and we'd better get comfortable with that posture."[77]

- Margaret Wheatley

For over three hundred years in western European culture, Newton's mechanistic reductionism has monopolized the worldview of how systems behave. It has only been in the last twenty-five years that a serious challenger has emerged; the new science of nonlinear dynamics. While initially receiving a lukewarm reception, nonlinear dynamics is now considered a significant construct for the information age.

The military C2 system and decisionmaking process did not become nonlinear with the arrival of the new science. They are *inherently* nonlinear. While true today, the future application of information age technologies will further change the C2 landscape from its current appearance. Though the exact form is impossible to predict, successful commanders will operate with an increased understanding that future C2 systems will be more nonlinear than the present. Without a new science worldview, military scientists developing C2 systems for the twenty-first century run the risk of visualizing them through seventeenth century eyes.

To ride the wave of technology rather than drown in it, the U.S. Marine Corps has boarded Sea Dragon. Analyzing this concept of advanced warfighting from the perspective of the new science reveals a philosophy and design in concert with the precepts of nonlinear dynamics: coordination rather than control, autonomous decisionmaking centers, and unconstrained information feedback. Led by commanders with the new science worldview, Sea Dragon's C2 system is capable of levels of responsiveness, flexibility, and adaptation unimaginable by Newtonian standards. As with all nonlinear creatures, the future direction that Sea Dragon takes will be unpredictable. By recognizing from the beginning its true nature as a chaotic and complex creature, the ride will not surprise the Corps.

ENDNOTES

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